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Helium Leak Testing of Appendage Welded PHWR Fuel Tubes

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Abstract

Nuclear Fuel Complex is catering the needs of all power reactors in India by supplying Fuel Bundles. PHWR Fuel Bundle consists of 19/37 fuel elements. Each fuel element contains UO_2 fuel pellets loaded in fuel tube of 0.4 mm thick, 13.8/15.3 mm dia and 500 mm length and ends are closed with end plugs by resistance welding. Appendages are welded on the fuel elements to facilitate inter element spacing for coolant flow in the fuel bundle. Any leakage of the fuel element welds can lead to high radioactive leakage.

At present the appendages are welded on the fuel element after loading of pellets and welding end plugs. However this appears to contribute to higher leak rates and more rejects in helium leak testing. In the case of MOX Fuel this process causes contamination due to weld leaks and reprocessing problems. Hence the procedure has been modified to weld the appendages on empty tubes and submit the same for leak testing. It may be noted that the performing leak testing of appendages welded empty tubes is a difficult task. A special set up has been prepared to perform this task.

This paper brings out in detail Helium Leak Testing methodology of appendage welded empty tubes and the benefits obtained.

Key words: *Appendage welds* **,** *Helium leak testing , through and through defects*

1. Introduction:

Nuclear Fuel Complex is manufacturing reactor grade fuel bundles required for reactors operating in the country. Two types of fuel bundles are made in NFC (1) Fuel bundle for Pressurised Heavy Water Reactor and 3. The fuel bundle for Boiling Water Reactors. Apart from manufacturing fuel bundles, NFC also makes Fuel sub assemblies to Fast Breeder reactors, other Structurals & Core components like Coolant tube, Calandria Tube, Reactivity mechanisms , SS tubes and high purity materials.

The fuel bundle required for Pressurised Heavy Water Reactor (PHWR) (Figure 1.) is a cluster of 19 / 37 fuel elements with their ends welded to a circular end plate.

FIG. 1 PHWR 19 Element Fuel Bundles

Each fuel element contains sintered UO_2 pellets inside them. The pellets are the source of nuclear energy producing electricity in the reactor. The fuel element is made from a thin zircalloy tube of 0.4 mm wall thickness, outer dia of 13.8 mm /15.3mm and length of 500mm.The ends of are sealed with end plugs by resistance welding.

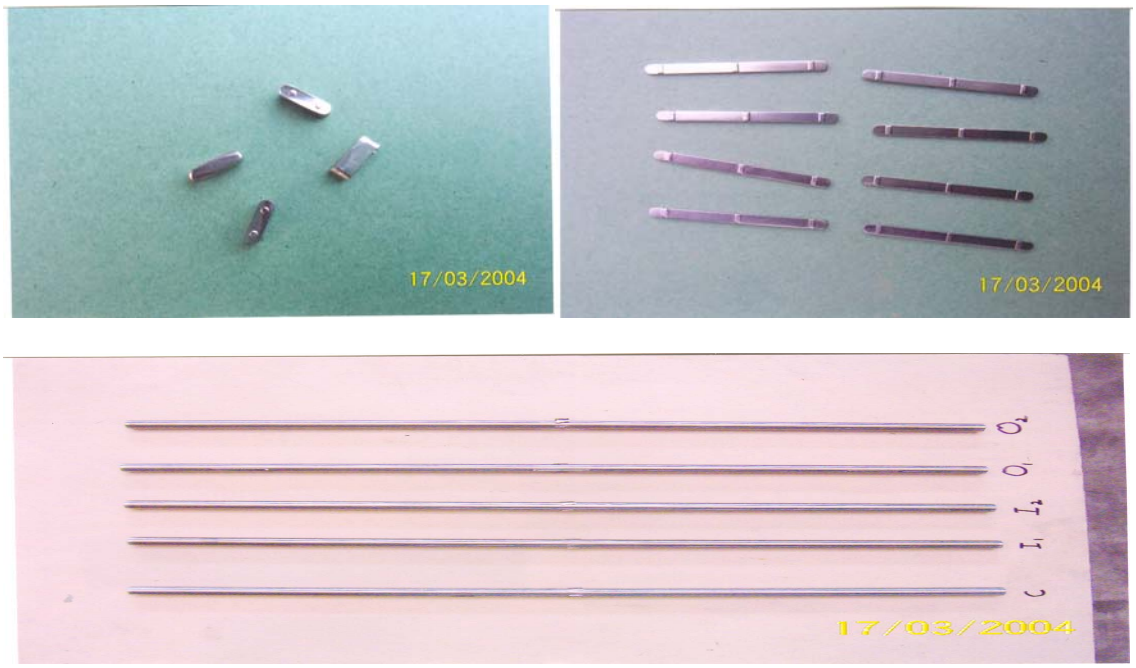

FIG.2 Fuel tubes with appendages

Appendages are welded on the fuel tube at specified locations by resistance spot welding to provide inter element spacing in the Fuel Bundle to facilitate uniform coolant flow. As the tube thickness is very small the weld integrity is difficult to control during process. The weld integrity is assured by sample destructive testing, Visual & Helium Leak testing of fuel elements.

2.Helium leak Testing

Helium Leak testing is the high sensitivity technique of all the leak testing methods. This method finds out very fine through and through defects in the welds or sheath, of the order of even $1x10^{-11}$ STD cc/sec and is one of the powerful tools to qualify the welds where leak tightness is required.

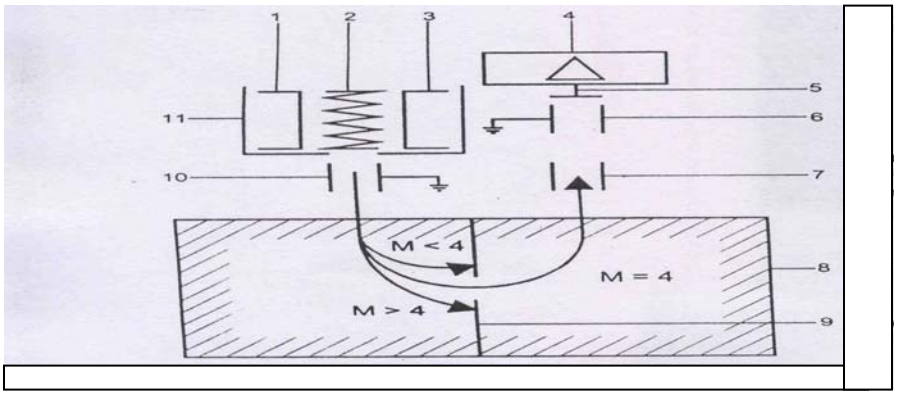

Fig.3 Mass spectrometer

Helium leak detector works on the principle of Mass Spectrometer. Mass spectrometer (Fig 3) ionizes the gases and separate the ionised helium from rest of the ions by employing constant magnetic field. Only Helium ions are allowed to fall on the collector and give rise to current proportional to the leak rate of helium from the defect. The equipment is calibrated with known helium leak standard and and then the unknown leaks are quantified.

3.Methods of Helium Leak Testing

There are various methods of leak testing as shown below

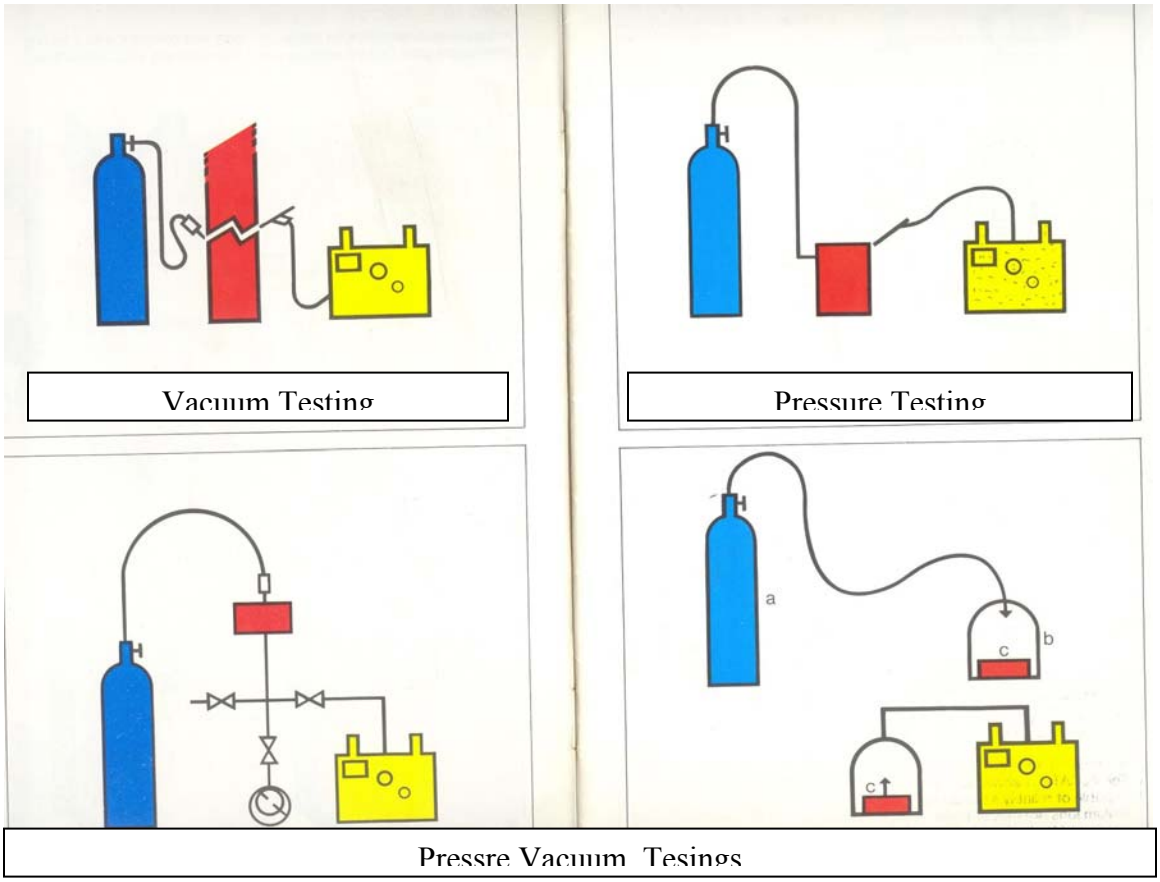

Fig. 4 Methods of Leak Testing

3.1 Vacuum method: - The component to be tested is evacuated by connecting to the mass spectrometer. Helium is sprayed on weld joints externally. Any through and through defect allows helium inside the vacuum system and to the mass spectrometer giving rise to signal in the leak detector .The sensitivity in this technique achieved can be $1x10^{-10}$, std. cc/sec.

3.2 Pressure method:- The component to be leak tested is pressurised with helium gas Any through & through defect will allow helium gas to leak to outside and a Sniffer probe attached to the leak detector sucks this gas into the detector where mass spectrometer detects the leak and quantifies the leak. As the helium is leaking in to the atmosphere and gets diluted due to diffusion , maximum sensitivity achieved ($5x10^{-8}$ std cc/sec) is poor in this technique compared to vacuum leak testing

3.3 Pressure vacuum method : - The component to be tested is filled with helium and placed inside a bell jar. The bell jar is then evacuated by helium leak detector connected to it, Helium gas from the defective portion leaks in to the evacuated bell jar and enters into the mass spectrometer to indicate the leak rate . As the helium gas is leaking in to the vacuum system directly there is no dilution of helium and sensitivity is highest in this method i.e. $5x10^{-11}$ and cc/sec. Hermetically sealed objects like electronic components can also be leak tested by this method by initial bombing / backfilling the objects with tracer gas in a chamber and then leak testing.

4. Helium Leak Testing of PHWR Fuel Elements & Bundles

In this method appendage welded Fuel elements are loaded into a test chamber, ten elements or one bundle at a time. Pressure Vacuum method is being used for testing, as the same is a high sensitivity technique.

Helium leak Testing of Fuel Bundle

The elements are already pressurised with helium inside above one atmosphere. The test chamber is then connected to HLD as in Fig 5 and evacuated. After initial evacuation to rough vacuum of 10^{-2} Torr, the test chamber is connected to the mass spectrometer detector cell through test valve for helium leak detection. The acceptable leak rate is $1x10^{-8}$ std cc/sec. After leak testing the test chamber is vented to remove the tested elements and a fresh batch of elements or bundles are loaded for next test.

5 . Calibration

5.1 For element leak testing :

Equipment calibration is done first by connecting the STD leak calibrator of 1.2 x 10^{-8} std cc/sec directly to the top port of the detector as in Fig 6. Then system calibration is done by placing the STD Leak calibrator in the test chamber at the farthest end.

Fig. 6 Equipment external calibration

Fig . 6a System calibration

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5.2 For appendage welded empty tube testing

Equipment calibration is similar, but system calibration was done specially in the following method as shown in the fig 6a.

- The fuel element with a leak in the appendage weld, is tested for the leak rate by bell jar method ie with helium inside the element and outside is evacuated keeping in vacuum chamber. The leak rate was observed to be $1.1x10^{-6}$std cc /sec.
- Then the same element is cut at one end and the pellets are unloaded and cleaned inside and outside .The open end is connected to the leak detector and evacuated. A special hood is introduced on the appendage welds of the tube and connected to the Helium cylinder . Helium in the hood leaked into the tube and entered the leak detector to indicate a leak rate of $1x10^{-6}$ std cc/sec .
- If leak rates from both the methods are not the same, leak rates from both the methods is compared to arrive at a calibration factor.
- Thus leak rate from unknown leaks can be calculated by the multiplying the observed leak rate with the calibration factor .

6.Helium Leak Testing of Appendage Welds on Empty Tubes.

As the tubes can not be pressurised with Helium in this method ,the tubes can be evacuated as a bunch and Helium is pressurized from outside. A special set up is made for evacuating the tubes as shown in Fig 7. The tubes are evacuated by introducing the

Helium leak testing of appendage welded Fuel tubes

one end of the tubes in to a big neoprene cork which can be fixed to an adopter connected to NW 40 opening of the Leak Detector port and closing the other ends with small rubber corks. Around the appendage welds of all the tubes, a special hood is introduced, which can be pressurized with Helium from a Cylinder .If any leak exists in the appendage welds, Helium leaks into the corresponding tube and enters the Leak detector to give the leak rate. The leaked tube can be identified by testing the tubes individually .If the leak rate is acceptable for group of tubes, then all the tubes are accepted.

6.1 Precautions

- Proper care must be taken to maintain the helium background to a minimum during testing.
- As helium is flowing out of the hood into the atmosphere at the time of test , testing shall not be done in enclosed rooms . Area open to outside atmosphere is preferable.
- Care must be taken to throw out the helium from the hood to out side,before venting the Leak detector port by arranging a fan in front of the chamber..

6.2 Advantages

- As the leak testing is done prior to pellet loading in the tube, it is ensured that appendages are leak tight and element rejection is minimised.
- The reliability of testing in empty tube form is more as Leak clogging in appendage welds due to powder from pellet is avoided.
- If this method is adopted for MOX fuel bundle production spillage of radioactive material and area contamination can be avoided.
- As the pellets are loaded after ensuring the appendage weld integrity, reprocessing the rejected elements is reduced.

7. Conclusions

- ✓ Helium leak testing of appendage welded empty tubes is possible by this method .
- ✓ There is scope for increasing the number of tubes tested in a single test by the fabrication of a chamber accommodating 20to 30 tubes, which can be evacuated from inside and pressurized with helium from outside .

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